

Patent Application

for:

DISCRETE FOURIER TRANSFORM (DFT) WATERMARK

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DISCRETE FOURIER TRANSFORM (DFT) WATERMARK

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is related to the following co-pending and commonly-assigned
5 patent applications:

U.S. Utility Patent Application Serial No. 10/419,490, filed on April 21, 2004, by
Ismael Rodriguez, entitled WATERMARKS FOR SECURE DISTRIBUTION OF
DIGITAL DATA, which application claims the benefit under 35 U.S.C. §119(e) of co-
pending and commonly-assigned U.S. Provisional Patent Application Serial No.

10 60/376,106, filed April 29, 2002, by Ismael Rodriguez, entitled WATERMARK
SCHEME FOR SECURE DISTRIBUTION OF DIGITAL IMAGES AND VIDEO,

U.S. Utility Patent Application Serial No. 10/419,491, filed on April 21, 2003, by
Ismael Rodriguez, entitled VISIBLE WATERMARK TO PROTECT MEDIA

CONTENT FROM A SERVER TO PROJECTOR, which application claims the benefit
15 under 35 U.S.C. §119(e) of co-pending and commonly-assigned U.S. Provisional Patent
Application Serial No. 60/376,303, filed April 29, 2002, by Ismael Rodriguez, entitled
VISIBLE WATERMARK TO PROTECT MEDIA CONTENT FROM A SERVER TO
PROJECTOR,

U.S. Utility Patent Application Serial No. 10/419,489, filed on April 21, 2003, by
20 Troy Rockwood and Wensheng Zhou, entitled NON-REPUDIATION

WATERMARKING PROTECTION BASED ON PUBLIC AND PRIVATE KEYS,
which application claims the benefit under 35 U.S.C. §119(e) of co-pending and
commonly-assigned U.S. Provisional Patent Application Serial No. 60/376,212, filed
April 29, 2002, by Troy Rockwood and Wensheng Zhou, entitled NON-REPUDIATION
25 WATERMARKING PROTECTION APPARATUS AND METHOD BASED ON
PUBLIC AND PRIVATE KEY,

U.S. Utility Patent Application Serial No. 10/419,495, filed on April 21, 2003, by
Wensheng Zhou and Phoom Sagetong, entitled DYNAMIC WAVELET FEATURE-
BASED WATERMARK, which application claims the benefit under 35 U.S.C. §119(e)

30 of co-pending and commonly-assigned U.S. Provisional Patent Application Serial No.
60/376,092, filed April 29, 2002, by Wensheng Zhou and Phoom Sagetong, entitled

DYNAMIC WAVELET FEATURE-BASED WATERMARK APPARATUS AND
METHOD FOR DIGITAL MOVIES IN DIGITAL CINEMA, and

U.S. Utility Patent Application Serial No. 10/131,104, filed on April 24, 2002, by
Troy Dean Rockwood, Bong Kyun Ryu, Wensheng Zhou and Yongguang Zhang, entitled
5 SYSTEM AND METHODS FOR DIGITAL CONTENT DISTRIBUTION,
all of which applications are incorporated by reference herein.

BACKGROUND OF THE INVENTION

1. Field of the Invention.

10 The invention relates to the field of digital watermarks, and more particularly, to a
Discrete Fourier Transform (DFT) watermark.

2. Description of the Related Art.

(This application references a number of publications, as indicated in the
15 specification by a reference number enclosed in brackets, e.g., [x]. These publications,
along with their associated reference numbers, are identified in the section below entitled
"References.")

With the recent growth of networked multimedia systems, techniques are needed
to prevent (or at least deter) the illegal copying, forgery and distribution of media content
20 comprised of digital audio, images and video. Many approaches are available for
protecting such digital data, including encryption, authentication and time stamping.

One way to improve a claim of ownership over digital data, for instance, is to
place a low-level signal or structure directly into the digital data. This signal or structure,
known as a digital watermark, uniquely identifies the owner and can be easily extracted
25 from the digital data. If the digital data is copied and distributed, the watermark is
distributed along with the digital data. This is in contrast to the (easily removed)
ownership information fields allowed by the MPEG-2 syntax.

Digital watermarking is an emerging technology. Several digital watermarking
methods have been proposed.

30 For example, Cox et al. in [1] proposed and patented a digital watermark
technology that is based on a spread spectrum watermark, wherein the watermark is

embedded into a spread spectrum of video signals, such as Fast Fourier Transform (FFT) or Discrete Cosine Transform (DCT) coefficients.

Koch, Rindfrey and Zhao in [2] also proposed two general watermarks using DCT coefficients. However, the resulting DCT has no relationship to that of the image and, consequently, may be likely to cause noticeable artifacts in the image and be sensitive to noise.

A scene-based watermark has been proposed by Swanson, Zhu and Tewfik in [3]. In this method, each of a number of frames of a scene of video data undergoes a temporal wavelet transform, from which blocks are extracted. The blocks undergo perceptual masking in the frequency domain, such that a watermark is embedded therein. Once the watermark block is taken out of the frequency domain, a spatial mask of the original block is weighted to the watermark block, and added to the original block to obtain the watermarked block.

Pereira and Pun [4] proposed inserting a registration pattern in the watermarked image and trying to identify and invert the geometric distortion before watermark detection. As pointed out by Lin et al. [5], there are problems with this solution. One problem is that it may reduce image quality due to insertion of the registration pattern. Another problem is the possibility of a collusion attack, because all the watermarked images share a common registration pattern.

In Lin [5], a Fourier-Mellin transform was used to embed a watermark, which was cast in a rotation-, scale-, and translation-invariant domain. To solve the problem of instability in inverting a log-polar re-sampling of the Fourier magnitude, an iterative method was proposed to approximate this step. However, this approach is computationally complex, which makes it unsuitable for realtime applications.

Earlier, Solachidis and Pitas [6] proposed a circular symmetric watermarking scheme in the DFT domain where each watermark bit was embedded in a section of a circular ring in the frequency domain. In the case of rotation, a search for the rotated angle needed to be performed to detect the watermark.

Regardless of the merits of prior art methods, there is a need for an improved watermark for digital data that prevents copying, forgery and distribution of media content. The present invention satisfies this need. More specifically, the goal of the

present invention is to provide unique, dynamic and robust digital watermarks for digital data, in order to trace any compromised copies of the digital data.

SUMMARY OF THE INVENTION

5 The present invention discloses a method and apparatus for embedding a watermark in digital data. A Y component of a Y, U(Cb), V(Cr) digital data stream representing color components of digital video is extracted as the digital data for embedding the watermark. The digital data is then scaled to a standard size. A Discrete Fourier Transform (DFT) is performed on the digital data, and a magnitude domain of the
10 Discrete Fourier Transform is computed. The watermark is embedded into selected frequency bands of the computed magnitude domain of the Discrete Fourier Transform, thereby creating a watermarked magnitude domain. The selected frequency bands comprise one or more middle frequency bands, and the middle frequency bands comprise a band of circular rings of the magnitude domain. An inverse Discrete Fourier Transform
15 is performed on the watermarked magnitude domain to reconstruct the digital data with the embedded watermark.

 The present invention also discloses a method and apparatus for detecting a watermark in digital data. A Y component of a Y, U(Cb), V(Cr) digital data stream representing color components of digital video is extracted as the digital data for
20 embedding the watermark. The digital data is then scaled to a standard size. A Discrete Fourier Transform (DFT) is performed on the digital data, and a magnitude domain of the Discrete Fourier Transform is computed. The watermark is detected and/or extracted from selected frequency bands of the computed magnitude domain of the Discrete Fourier Transform. The selected frequency bands comprise one or more middle
25 frequency bands, and the middle frequency bands comprise a band of circular rings of the magnitude domain.

BRIEF DESCRIPTION OF THE DRAWINGS

 Referring now to the drawings in which like reference numbers represent
30 corresponding parts throughout:

FIGS. 1A and 1B depict a top-level functional block diagram of one embodiment of a media content distribution system;

FIGS. 2A-2F, which illustrate the relationship of DFT coefficients of an original signal, down-sampled signal, and the down-sampled signal after being up-sampled;

5 FIG. 3 is a flow chart that illustrates the logic of the watermarking embedding algorithm according to a preferred embodiment of the present invention;

FIG. 4 is a flow chart of the watermark detection algorithm according to a preferred embodiment of the present invention;

FIG. 5 show the original unwatermarked Lena image;

10 FIG. 6 shows the watermarked Lena image;

FIG. 7A shows the difference between the original image and the watermarked image;

FIG. 7B shows the difference of the DFT magnitude between the original image and the watermarked image;

15 FIG. 8 shows the results of the computing the PSNR (Peak Signal to Noise Ratio) of the watermarked image as a function of embedding strength λ and the embedding bands $\{B_i\}$;

FIG. 9 shows the rescaled Lena image of the image down-scaled by a factor 0.4375;

20 FIG. 10 shows the results of the correlation detection for scaling factors of 0.75, 0.5, 0.4375 and 0.3125;

FIG. 11 shows the image rotated counter-clockwise by 30° ;

FIG. 12 shows the results of correlation detection for a set of images rotated by angles -3° , 5° , 30° and 45° ;

25 FIG. 13 shows the correlation detection responses of cropped images with cropping ratios (in both dimensions) of 0.125, 0.5, 0.7812 and 0.9453;

FIG. 14 shows the compressed Lena image with quality 7%;

FIG. 16 show the correlation detector responses of JPEG compressed images with compression quality parameters of 95%, 50%, 20% and 7%;

30 FIG. 16 shows a correlation detection response to an attacked image;

FIG. 17 shows a somewhat noisy correlation response;

FIG. 18 shows a correlation response for an average correlation of 0.885266;
FIGS. 19 and 20 show the correlation responses for embedding strengths 0.3 and
0.5, respectively.

DETAILED DESCRIPTION OF THE INVENTION

In the following description of the preferred embodiment, reference is made to the
accompanying drawings which form a part hereof, and in which is shown by way of
illustration a specific embodiment in which the invention may be practiced. It is to be
understood that other embodiments may be utilized and structural changes may be made
without departing from the scope of the present invention.

1. Overview

The present invention comprises a novel watermarking embedding and detection
apparatus and method for digital images/videos. A Y (luminance) component is
extracted as digital data from a Y, U(Cb), V(Cr) digital data stream representing the color
components of the digital images/video, the digital data is scaled to a standard size, a
DFT (Discrete Fourier Transform) is performed on the standard size digital data, the
magnitude domain of the DFT is computed, a watermark comprised of a pattern or vector
of W bits is cast or embedded into selected frequency bands of the computed magnitude
domain, thereby creating a watermarked magnitude domain, and then an inverse DFT is
performed on the watermarked magnitude domain to reconstruct the digital data with the
embedded watermark.

The watermark is robust, in that it survives a number of different attacks, such as
compression, rotation, cropping, scaling, etc. Experiments show that the watermark can
survive such attacks due to advantages in rotation and scaling invariance of the DFT.

The payload of the watermark is large enough that each watermark may be
unique. Moreover, the watermark may be created dynamically, for example, according to
the time and place of presentation, and thus is appropriate for realtime applications.
Consequently, the watermark may operate as a unique label for the images/video, and
thus protect the copyright of the images/video.

Detection of the watermark can be oblivious, which means that it does not require the original images/video, or semi-oblivious, which means that it only requires limited information from the original images/video.

5 2. Hardware Environment

FIGS. 1A and 1B depict a top-level functional block diagram of one embodiment of a media content distribution system 100. The media content distribution system 100 comprises a content provider 102, a protection entity 104, a distribution entity 106 and one or more presentation/displaying entities 108. The content provider 102 provides
10 media content 110 such as audiovisual material to the protection entity 104. The media content 110, which can be in digital or analog form, can be transmitted in electronic form via the Internet, by dedicated land line, broadcast, or by physical delivery of a physical embodiment of the media (e.g. a celluloid film strip, optical or magnetic disk/tape). Content can also be provided to the protection entity 104 from a secure archive facility
15 112.

The media content 110 may be telecined by processor 114 to format the media content as desired. The telecine process can take place at the content provider 102, the protection entity 104, or a third party.

The protection entity 104 may include a media preparation processor 116. In one
20 embodiment, the media preparation processor 116 includes a computer system such as a server, having a processor 118 and a memory 120 communicatively coupled thereto. The protection entity 104 further prepares the media content 110. Such preparation may include adding protection to the media content 110 to prevent piracy of the media content 110. For example, the preparation processor 116 can perform a watermarking process
25 122, apply a compression process 124, and/or perform an encrypting process 126 on the media content 110 to protect it, resulting in output digital data 128. Thus, the output digital data 128 may contain one or more data streams that has been watermarked, compressed and/or encrypted.

Once prepared, the output digital data 128 can be transferred to the distribution
30 entity 106 via digital transmission, tape or disk (e.g., CD-ROM, DVD, etc.). Moreover,

the output digital data 128 can also be archived in a data vault facility 130 until it is needed.

Although illustrated as separate entities, the protection entity 104 can be considered as part of the distribution entity 106 in the preferred embodiment and is
5 communicatively positioned between the content provider 102 and the distribution entity 106. This configuration ameliorates some of the security concerns regarding the transmission of the output digital data 128 between the protection entity 104 and the distribution entity 106. In alternative embodiments, however, the protection entity 104 could be part of the content provider 102 or displaying entity 108. Moreover, in
10 alternative embodiments, the protection entity 104 could be positioned between the distribution entity 106 and the displaying entity 108. Indeed, it should be understood that the protection entity 104, and the functions that it performs, may be employed whenever and wherever the media content 110 moves from one domain of control to another (for example, from the copyright holder to the content provider 102, from the content
15 provider 102 to the distribution entity 106, or from the distribution entity 106 to the display entity 108).

The distribution entity 106 includes a conditional access management system (CAMS) 132, that accepts the output digital data 128, and determines whether access permissions are appropriate for the output digital data 128. Further, CAMS 132 may be
20 responsible for additional encrypting so that unauthorized access during transmission is prevented.

Once the output digital data 128 is in the appropriate format and access permissions have been validated, CAMS 132 provides the output digital data 128 to an uplink server 134, ultimately for transmission by uplink equipment 136 to one or more
25 displaying entities 108, as shown in FIG. 1B. This is accomplished by the uplink equipment 136 and uplink antenna 138.

In addition or in the alternative to transmission via satellite, the output digital data 128 can be provided to the displaying entity 108 via a forward channel fiber network 140. Additionally, the output digital data 128 may be transmitted to displaying entity 108 via a
30 modem 142 using, for example a public switched telephone network line. A land based communication such as through fiber network 140 or modem 142 is referred to as a back

channel. Thus, information can be transmitted to and from the displaying entity 108 via the back channel or the satellite network. Typically, the back channel provides data communication for administration functions (e.g. keys, billing, authorization, usage tracking, etc.), while the satellite network provides for transfer of the output digital data 128 to the displaying entities 108.

The output digital data 128 may be securely stored in a database 144. Data is transferred to and from the database 144 under the control and management of the business operations management system (BOMS) 146. Thus, the BOMS 146 manages the transmission of information to 108, and assures that unauthorized transmissions do not take place.

Referring to FIG. 1B, the data transmitted via uplink 148 is received in a satellite 150A, and transmitted to a downlink antenna 152, which is communicatively coupled to a satellite or downlink receiver 154.

In one embodiment, the satellite 150A also transmits the data to an alternate distribution entity 156 and/or to another satellite 150B via crosslink 158. Typically, satellite 150B services a different terrestrial region than satellite 150A, and transmits data to displaying entities 108 in other geographical locations.

A typical displaying entity 108 comprises a modem 160 (and may also include a fiber receiver 158) for receiving and transmitting information through the back channel (i.e., via an communication path other than that provided by the satellite system described above) to and from the distribution entity 106. For example, feedback information (e.g. relating to system diagnostics, keys, billing, usage and other administrative functions) from the exhibitor 108 can be transmitted through the back channel to the distribution entity 106. The output digital data 128 and other information may be accepted into a processing system 164 (also referred to as a content server). The output digital data 128 may then be stored in the storage device 166 for later transmission to displaying systems (e.g., digital projectors) 168A-168C. Before storage, the output digital data 128 can be decrypted to remove transmission encryption (e.g. any encryption applied by the CAMS 132), leaving the encryption applied by the preparation processor 116.

When the media content 110 is to be displayed, final decryption techniques are used on the output digital data 128 to substantially reproduce the original media content

110 in a viewable form which is provided to one or more of the displaying systems 168A-168C. For example, encryption 126 and compression 124 applied by the preparation processor 118 is finally removed, however, any latent modification, undetectable to viewers (e.g., the results from the watermarking process 122) is left intact. In one or more embodiments, a display processor 170 prevents storage of the decrypted media content 110 in any media, whether in the storage device 166 or otherwise. In addition, the media content 110 can be communicated to the displaying systems 168A-168C over an independently encrypted connection, such as on a gigabit LAN 172.

Generally, each of the components of the system 100 comprise hardware and/or software that is embodied in or retrievable from a device, medium, signal or carrier. Moreover, this hardware and/or software perform the steps necessary to implement and/or use the present invention. Thus, the present invention may be implemented as a method, apparatus, or article of manufacture.

Of course, those skilled in the art will recognize that many modifications may be made to the configuration described without departing from the scope of the present invention. Specifically, those skilled in the art will recognize that any combination of the above components, or any number of different components, may be used to implement the present invention, so long as similar functions are performed thereby.

2. Watermarking Process

In the preferred embodiment, a DFT is performed on size-standardized digital data comprising a Y (luminance) component extracted from a Y, U(Cb), V(Cr) digital data stream representing the color components of the digital images/video. Then, the magnitude domain of the DFT is computed. A watermark comprised of a vector of W bits is cast or embedded in selected frequency bands of the computed magnitude domain, thereby creating a watermarked magnitude domain. Finally, an inverse DFT is performed on the watermarked magnitude domain to reconstruct the digital data with the embedded watermark.

In a preferred embodiment, the present invention is used for secure digital movie distribution systems, such as described in U.S. Utility Patent Application Serial No. 10/131,104, filed on April 24, 2002, by Troy Dean Rockwood, Bong Kyun Ryu,

Wensheng Zhou and Yongguang Zhang, entitled SYSTEM AND METHODS FOR DIGITAL CONTENT DISTRIBUTION, which application is incorporated by reference herein.

5 The preferred embodiment of the present invention also complements the general concept of dynamic feature-based watermarks described in U.S. Utility Patent Application Serial No. 10/419,495, filed on April 21, 2003, by Wensheng Zhou and Phoom Sagetong, entitled DYNAMIC WAVELET FEATURE-BASED WATERMARK, which application claims the benefit under 35 U.S.C. §119(e) of co-pending and commonly-assigned U.S. Provisional Patent Application Serial No. 60/376,092, filed 10 April 29, 2002, by Wensheng Zhou and Phoom Sagetong, entitled DYNAMIC WAVELET FEATURE-BASED WATERMARK APPARATUS AND METHOD FOR DIGITAL MOVIES IN DIGITAL CINEMA, which application is incorporated by reference herein.

15 In addition, the preferred embodiment of the present invention complements the general concept of non-repudiation watermarking described in U.S. Utility Patent Application Serial No. 10/419,489, filed on April 21, 2003, by Troy Rockwood and Wensheng Zhou, entitled NON-REPUDIATION WATERMARKING PROTECTION BASED ON PUBLIC AND PRIVATE KEYS, which application claims the benefit under 35 U.S.C. §119(e) of co-pending and commonly-assigned U.S. Provisional Patent 20 Application Serial No. 60/376,212, filed April 29, 2002, by Troy Rockwood and Wensheng Zhou, entitled NON-REPUDIATION WATERMARKING PROTECTION APPARATUS AND METHOD BASED ON PUBLIC AND PRIVATE KEY, which application is incorporated by reference herein.

25 2.1. Discrete Fourier Transform

In the present invention, the DFT of an $N_1 \times N_2$ image $i(n_1, n_2)$ is computed as:

$$F(k_1, k_2) = \sum_{n_1=0}^{N_1-1} \sum_{n_2=0}^{N_2-1} i(n_1, n_2) \exp^{-j2\pi n_1 k_1 / N_1 - j2\pi n_2 k_2 / N_2} \quad (1)$$

30 where:

N_1 is the number of pixels on a first axis of the image,
 N_2 is the number of pixels on a second axis of the image,
 i is an image buffer of two dimensions,
 n_1 is an index to a first dimension of the image buffer,
 n_2 is an index to a second dimension of the image buffer,
 F is a Fourier transform,
 k_1 is a continuous function of a first variable along the first axis,
 k_2 is a continuous function of a first variable along the second axis, and
 j is the square root of -1 .

Translation in the spatial domain will have no effect on the magnitude of a Fourier transform as shown in Equation 2. Instead, it only causes a phase shift.

$$|DFT(i(n_1 + t_1, n_2 + t_2))| = |DFT(i(n_1, n_2))| \quad (2)$$

where:

t_1 is a first time sequence,
 t_2 is a second time sequence, and
 DFT is a Discrete Fourier Transform.

When the image $i(n_1, n_2)$ is rotated a degrees in the spatial domain, it will cause the same rotation in the frequency domain:

$$DFT(i(n_1 \cos a - n_2 \sin a, n_1 \sin a + n_2 \cos a)) = F(i(k_1 \cos a - k_2 \sin a, k_1 \sin a + k_2 \cos a)) \quad (3)$$

If it is assumed that a fixed-size DFT is performed on the original and scaled images, then scaling in the spatial domain causes inverse scaling in the Fourier domain, as shown in Equation 4. If an image is down-sampled, an alias effect will occur in the high frequency bands.

$$DFT(i(\sigma n_1, \sigma n_2)) = \frac{1}{\sigma} F\left(\frac{k_1}{\sigma}, \frac{k_2}{\sigma}\right) \quad (4)$$

where:

σ is a scaling factor.

In order to cope with this problem, some pre-processing needs to be performed before applying the Fourier transform to the image. The image is first scaled to a standard size (512 x 512, for example), then a FFT (Fast Fourier Transform) of the same size is performed on the resulting image. The same pre-processing is used by the watermark detection algorithm.

The benefit of doing this can be clarified by a simplified example in FIGS. 2A-2F, which illustrate the relationship of DFT coefficients of an original signal, down-sampled signal, and the down-sampled signal after being up-sampled. FIG. 2A is an original 16-point signal, FIG. 2B is the original signal of FIG. 2A down-sampled by 2, and FIG. 2C is the down-sampled signal of FIG. 2B up-sampled by 2. FIGS. 2D, 2E, and 2F are the 16-point Fourier Transform coefficients of the original signal of FIG. 2A, the down-sampled signal of FIG. 2B, and the up-sampled signal of FIG. 2C, respectively. Note that the Fourier Transform of the down-sampled signal shown in FIG. 2E is a scaled and aliased version of the Fourier Transform of the original signal shown in FIG. 2D. Then, the re-scaled (up-sampled) signal is obtained by interpolating the down-sampled signal and FIG. 2F shows its 16-point Fourier transform coefficients. In FIG. 2F, it can be seen that, after re-scaling the down-sampled signal back to its original size by interpolation, the Fourier transform coefficients closely represent the original ones in FIG. 2D.

2.2. Watermark Embedding

FIG. 3 is a flow chart that illustrates the logic of the watermarking embedding algorithm according to a preferred embodiment of the present invention. In the preferred embodiment, this logic is performed by the watermarking process 122, but it may be performed by other entities in alternative embodiments.

Block 300 represents the watermarking process 122 receiving and initially processing the original images/video, e.g., an MPEG video stream. In this Block, the images/video may first be decoded using an MPEG decoder and then the Y (luminance) component of a Y, U(Cb), V(Cr) digital data stream representing the color components of

the digital images/video may be extracted. This extracted Y component comprises the digital data processed by the remaining steps of the logic.

Block 302 represents the watermarking process 122 scaling the digital data to a standard size.

5 Block 304 represents the watermarking process 122 performing a DFT on the size-standardized digital data.

Block 306 represents the watermarking process 122 computing the magnitude domain of the DFT.

10 Block 308 represents the watermarking process 122 obtaining a watermark comprised of a pattern or vector of W bits.

Block 310 represents the watermarking process 122 casting or embedding the watermark into selected frequency bands of the magnitude domain of the DFT, thereby creating a watermarked magnitude domain.

15 Block 312 represents the watermarking process 122 performing an inverse DFT on the watermarked magnitude domain to reconstruct the digital data with the embedded watermark.

Block 314 represents the watermarking process 122 outputting a watermarked version of the images/video. In this Block, the digital data, which comprises the Y (luminance) component of a Y, U(Cb), V(Cr) digital data stream representing the color
20 components of the digital images/video, is reinserted into the Y, U(Cb), V(Cr) digital data stream, resulting in the watermarked version of the digital images/video.

2.3 Embedding the Watermark

25 In Block 310, the selected frequency bands are middle frequency bands, wherein the middle frequency bands comprise a band of circular rings of the magnitude domain of the DFT. The width and location of the bands are empirically chosen, and they are also chosen based on the watermark payload (how many bits need to be embedded into each image) and the content of the image.

30 Specifically, a high frequency band renders the watermark vulnerable to image processing operations, such as low-pass filtering and compression. A low frequency

band renders the watermark visible in the images/video. Consequently, the selected frequency bands comprise middle frequency bands, in the preferred embodiment.

The watermark is a vector $W = \{w_1, w_2, \dots, w_k\}$ of k bits, which has the same number of 1s and -1s in order to obtain a zero mean. Each bit w_i is embedded into a

5 band of circular rings $B_i = \{M(k_1, k_2), R_{i,l} \leq \sqrt{k_1^2 + k_2^2} \leq R_{i,h}\}$, where $R_{i,l}$ and $R_{i,h}$ are, respectively, the inner and outer boundaries of the band B_i and $M(k_1, k_2)$ are the magnitude coefficients.

Let e_i be the feature element in the i th band:

$$10 \quad e_i = \sum_{(k_1, k_2) \in B_i} M(k_1, k_2) \quad (5)$$

wherein:

a feature vector $E = \{e_1, e_2, \dots, e_k\}$ is comprised of l_i norms of each band.

A multiplicative embedding function is used, since it is signal adaptive. When
15 watermark bit w_i is inserted into the i th band, the modified feature e'_i is:

$$e'_i = e_i(1 + \lambda w_i) \quad (6)$$

where λ is the embedding strength. It can be seen that the present invention
20 could simply modify each coefficient $M(k_1, k_2) \in B_i$ accordingly:

$$M'(k_1, k_2) = M(k_1, k_2)(1 + \lambda w_i) \quad (7)$$

Now, with the modified magnitude coefficients M' and phase P unchanged, the
25 inverse DFT (IDFT) is performed to obtain the watermarked image $i'(n_1, n_2)$:

$$i' = IDFT(M', P) \quad (8)$$

2.4 Watermark Detection

FIG. 4 is a flow chart of the watermark detection algorithm according to a preferred embodiment of the present invention. In the preferred embodiment, this logic is performed by the content provider 102, but it may be performed by other entities in alternative embodiments.

Block 400 represents the content provider 102 receiving and initially processing the watermarked images/video, denoted as $i'(n_1, n_2)$. In this Block, the watermarked images/video may first be decoded using an MPEG decoder and then the Y (luminance) component of a Y, U(Cb), V(Cr) digital data stream representing the color components of the digital images/video may be extracted. This extracted Y component comprises the digital data processed by the remaining steps of the logic.

Block 402 represents the content provider 102 scaling the digital data to a standard size.

Block 404 represents the content provider 102 performing a DFT on the size-standardized digital data.

Block 406 represents the content provider 102 computing a magnitude domain of the DFT.

Block 408 represents the content provider 102 detecting and/or extracting the watermark from selected frequency bands of the computed magnitude domain of the DFT. As with FIG. 3 above, the selected frequency bands comprise one or more middle frequency bands, wherein the middle frequency bands comprise a band of circular rings of the magnitude domain.

Block 410 represents the content provider 102 outputting the detected watermark as a vector W .

2.5 Detecting and/or Extracting the Watermark

In Block 408, using the same set of bands of rings $\{B_i\}$ as were used in embedding the watermark, the feature element e_i of each band is computed. According to Equation 6, each bit w_i^d of the watermark vector W can be extracted as:

$$w_i^d = \frac{e'_i - e_i}{\lambda e_i} \quad (9)$$

where:

- 5 d denotes that the watermark bit w_i^d is extracted from a distorted image and is different from the original embedded watermark bit w_i .

The image distortion is introduced due to either general signal processing or intentional attacks. A simple post-processing can be added, as in [3], to the watermark extraction to improve the correlation detection performance:

$$10 \quad w_i^* = w_i^d - \text{mean}(w^d) \quad (10)$$

where:

w_i^* is the extracted watermark bit, and

$\text{mean}(w^d)$ denotes the mean value of the extracted watermark bits.

- 15 In Block 408, a correlation-based detector is employed to decide whether a certain watermark signal is present in the image or not. The correlation between the extracted watermark signal and the original watermark signal is computed as:

$$C = \frac{W^* \cdot W}{|W^*| \cdot |W|} \quad (11)$$

20

where:

W^* is the extracted watermark vector and

W is the original embedded watermark vector.

- 25 Then, the presence of a watermark signal is determined by performing a hypothesis test using a threshold T :

H_0 : Watermark is present if $C > T$

H_1 : Watermark is not present otherwise

The choice of threshold T is a typical estimation problem and will affect the detection rate and false alarms of the system. In one experiment, it was set to 0.5 for simplicity. And, in the scenario of copyright tracking for digital cinema, there is a need to trace the origin of the illegal copies. Peak correlation detection could also be used to determine from which theater and at what time the copy was generated.

3. Experimental Results and Discussion

A series of experiments were performed on a 512 x 512 "Lena" image to test the robustness of the proposed watermarking algorithm to geometric attacks. The algorithm has also been implemented in C for MPEG-2 video sequences and embedded into the MPEG-2 decoder.

For video sequences, the watermark is cast into the luminance component of each frame. A 16-bit watermark $\{-1,1,1,1,-1,-1,1,1,1,-1,-1,-1,-1,1\}$ was used for all experiments. A set of 1024 watermarked sequences that are orthogonal to the given watermark are generated to represent different theater identifications. During watermark detection, the peak correlation of the extracted signal with one of the watermarked sequences is found to decide which watermark is actually present in the image. Images are scaled to a standard size 512 x 512 and 512-point FFT is performed. Finally, the experiments were categorized into multiple subsections based on the reducing visual quality and robustness against various attacks.

3.1. Perceptual Quality

FIG. 5 show the original unwatermarked Lena image and FIG. 6 shows the watermarked Lena image. In this case, the embedding strength was set to $\lambda = 0.1$, and $R_{1,l} = 28, R_{1,h} = 32, R_{16,h} = 107$. Each band has width 5 and all bands are continually located.

It can be seen that the watermark is invisible. The difference between the original image and the watermarked image is shown in FIG. 7A; and the difference of the DFT magnitude between the original image and the watermarked image is shown in FIG. 7B. Note that the difference value has been multiplied by a factor of 10 for clearer

illustration. FIG. 8 shows the results of the computing the PSNR (Peak Signal to Noise Ratio) of the watermarked image as a function of embedding strength λ and the embedding bands $\{B_i\}$. It can be seen that as the embedding bands are moved towards a higher frequency, the PSNR performance improves. In real applications, there is a tradeoff between the quality of the watermarked image and the robustness of the watermark.

3.2. Scaling

The watermarked image was scaled to different fractions of its original size, in order to demonstrate that the watermark detection works for scale factors down to 0.3125. In this case, where the scaled image area is only about 10 percent of the original image area, the correlation of the detected watermark signal and the right watermark signal is still well above any correlation with the others. FIG. 9 shows the rescaled Lena image of the image down-scaled by a factor 0.4375. It can be seen that a lot of the detail of the original image has been lost due to the down-scaling. The results of the correlation detection are shown in FIG. 10 for scaling factors of 0.75, 0.5, 0.4375 and 0.3125.

3.3. Rotation

The image was also rotated by a set of angles. Since the watermark detection is based on a global feature in a circular band of rings, there was no need to search for possible rotated angles. FIG. 11 shows the image rotated counter-clockwise by 30°. FIG. 12 shows the results of correlation detection for a set of images rotated by angles -3°, 5°, 30° and 45°. From the results, it can be seen that the algorithm is very effective for image rotations.

3.4. Cropping

The watermarked image were cropped in both dimensions, with only the central part of the image left. The cropped part of the image was replaced by the corresponding part of the original unwatermarked image. FIG. 13 shows the correlation detection responses of cropped images with cropping ratios (in both dimensions) of 0.125, 0.5, 0.7812 and 0.9453. It can be seen that the correlation with the right watermark is well

above the correlation with the others even when the cropping ratio is increased up to 0.7812. However, when the major part of the image is cropped, the response gets fuzzy.

3.5. Compression

5 Compression was performed on the watermarked image, and the results show that the watermark can still be detected when the compression quality parameter is down to 7%. FIG. 14 shows the compressed Lena image with quality 7%. It can be seen that the image is visibly distorted and the blocking effect of DCT coding is clearly seen. The correlation detector responses of JPEG compressed images with compression quality
10 parameters of 95%, 50%, 20% and 7% are shown in FIG. 15. The compression ratios for the Lena image under these quality factors are 2.85:1, 12.36:1, 20.76:1 and 34.03:1.

3.6. Combined Geometric Attack

15 A combined geometric transformation was also performed on the watermarked image. The image was first cropped to 448 x 448 and rotated counter-clockwise by 5 degrees, and then scaled to 256 x 256. FIG. 16 shows the correlation detection response to the attacked image. It can be seen that the correlation with the correct watermark is 0.9072, and again well above the correlation with other sequences.

3.7. Camcorder Recording Attack

20 The watermarked Lena image was also recorded with a camcorder. First, the embedding bands were set starting from 18 ($R_{1,l} = 18$). With embedding strength $\lambda = 0.1$, the average correlation of the detected watermark with the original watermark was 0.628967 over 10 recorded images and 9 out of 10 were correctly detected. FIG. 17
25 shows the somewhat noisy correlation response for this case. Then, with the same embedding location, the embedding strength was increased to 0.3. Now, an average correlation of 0.885266 was obtained and FIG. 18 shows the correlation response.

 Then, the embedding bands was moved towards a higher frequency with $R_{1,l} = 28$. And, the cases with embedding strengths 0.3 and 0.5 were tested. FIGS. 19
30 and 20 show the correlation responses for these two cases. The average correlations with the watermark were 0.817422 for $\lambda = 0.3$ and 0.894329 for $\lambda = 0.5$.

Thus, the correlation response becomes stronger as the embedding strength is increased or the embedding location is moved towards low frequency bands. This is the tradeoff between the robustness of the watermark and the visual quality of the watermarked image.

5

4. Summary

The present invention introduces a novel watermark algorithm to embed and detect a watermark pattern by exploiting the characteristics of DFT transformation of images/videos. The present invention implements a DFT feature-based watermarking algorithm resilient to geometric attacks. The watermark bits are spread into sets of circular bands in the amplitude of the DFT domain. The watermarking scheme is resilient to image scaling, rotation, cropping and JPEG compression. For video sequences, the watermark is embedded into the luminance component of each frame.

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5. References

The following references are incorporated by reference herein:

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- [3] M.D. Swanson, B. Zhu, and A. H. Tewfik, "Multiresolution scene-based video watermarking using perceptual models," IEEE Journal on Selected Areas in Communications, Vol. 16, No. 4, pp. 540-550, May 1998.
- 25 [4] S. Pereira and T. Pun. Fast Robust Template Matching for Affine Resistant Image Watermarks. "Proc. 3rd Int. Information Hiding Workshop, 207-218, 1999.
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[7] R. B. Wolfgang, C. I. Podilchuk, and E. J. Delp, "Perceptual watermarks for digital images and videos," Proceedings of the IEEE, Special Issue on Identification and Protection of Multimedia Information, Vol. 87, No. 7, pp. 1108-1126, July 1999.

5 6. Conclusion

 This concludes the description of the preferred embodiment of the invention. The following describes some alternative embodiments for accomplishing the present invention. For example, different types of digital data, transformation and feature selection could be used with the present invention. In addition, different sequences of
10 functions could be used than those described herein.

 In summary, the present invention discloses a method and apparatus for embedding a watermark in digital data. A Y component of a Y, U(Cb), V(Cr) digital data stream representing color components of digital video is extracted as the digital data for embedding the watermark. The digital data is then scaled to a standard size. A Discrete
15 Fourier Transform (DFT) is performed on the digital data, and a magnitude domain of the Discrete Fourier Transform is computed. The watermark is embedded into selected frequency bands of the computed magnitude domain of the Discrete Fourier Transform, thereby creating a watermarked magnitude domain. The selected frequency bands comprise one or more middle frequency bands, and the middle frequency bands comprise
20 a band of circular rings of the magnitude domain. An inverse Discrete Fourier Transform is performed on the watermarked magnitude domain to reconstruct the digital data with the embedded watermark.

 The present invention also discloses a method and apparatus for detecting a watermark in digital data. A Y component of a Y, U(Cb), V(Cr) digital data stream
25 representing color components of digital video is extracted as the digital data for embedding the watermark. The digital data is then scaled to a standard size. A Discrete Fourier Transform (DFT) is performed on the digital data, and a magnitude domain of the Discrete Fourier Transform is computed. The watermark is detected and/or extracted from selected frequency bands of the computed magnitude domain of the Discrete
30 Fourier Transform. The selected frequency bands comprise one or more middle

frequency bands, and the middle frequency bands comprise a band of circular rings of the magnitude domain.

The foregoing description of the preferred embodiment of the invention has been presented for the purposes of illustration and description. It is not intended to be

5 exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching.